

Summary Abstract: The National Bureau of Standards orifice-flow primary high vacuum standard

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The National Bureau of Standards (NBS) has constructed an orifice-flow primary pressure standard for use in the high vacuum range and below. This type device generates a known pressure difference by passing a measured flow of gas through a calculated conductance (the orifice). This type standard has been treated in recent reviews.^{1,2} The NBS standard differs from similar devices in the construction of the orifice; the use of a molecular drag gauge (MDG) to measure the pressure ratio across the orifice, allowing the calculation of the absolute pressure on the upstream side of the conductance; and the use of multiple injection points for the gas flow to extend the range to lower pressures. A detailed error analysis and description of the design and construction of this standard is being prepared for future publication.

The vacuum chamber of the standard has two cylindrical halves, 27 cm in diameter and 34 cm long, separated in the middle by a wall containing the orifice. The upper half includes eight ports for the attachment of gauges to be calibrated and a gas inlet with baffle. The lower half includes a second gas inlet and baffle, and is pumped by a nominal 0.5 m³/s turbomolecular pump. The chamber is stainless steel and metal seals are used throughout. The chamber and all attached gauges are routinely baked between 200 and 250 °C at the beginning of each calibration series. The orifice is fabricated in a separate orifice-plate that is sealed in the wall between the chamber halves by a gallium seal. During pump-down and bakeout the orifice-plate can be lifted away from the gallium seal, opening a 12.5 cm diam hole between the chamber halves. Base pressures for this system are typically 10⁻⁸ Pa (1 Torr = 133.3 Pa), almost exclusively hydrogen.

The 1.125 cm diam orifice was constructed by drilling a 1.12 cm diam hole through a 0.74 mm thick stainless steel plate, and then lapping the edges of the hole with 5/8 in. diam ball bearings from both sides until the concave spherical surfaces met in the center of the plate. The two lapped surfaces form a sharp burr-free edge. The spherical surfaces simplify the calculation of the transmission probability of the ducts above and below the orifice. The total uncertainty in the calculated conductance is estimated to be 0.8%, most of which is due to uncertainties in the measured dimensions of the orifice and duct.

A molecular drag (spinning rotor or viscosity) gauge is connected through bakable valves to the upper and lower chamber halves. Since it is inert (no hot filament) it can be alternately valved to measure the pressures above P_u and below P_l the orifice. Since it is linear in the molecular flow regime these measured values can be used to compute the ratio of those pressures, $R_p = P_u/P_l$. This can be combined with the calculated conductance C and the measured gas

flow into the upper chamber Q_u to give the pressure in the upper chamber,

$$P_u = P_l + \frac{Q_u}{C} \\ = \frac{Q_u R_p}{C(R_p - 1)} \quad (1)$$

The accuracy of R_p is limited by pressure gradients of a few percent in the lower chamber. However, R_p is large enough ($R_p = 26$ for N_2) that the error in $R_p/(R_p - 1)$ is correspondingly reduced.

The lower limit of this standard is determined by the hydrogen base pressure and the irreproducibility of the flowmeter. The latter is currently about 10⁻¹² mol/s. This limit can be partially circumvented by introducing the measured gas flow downstream from the orifice since, for a given pressure, a larger flow (about a factor of 26 for nitrogen) is required if the flow is introduced below the orifice than if it is introduced in the normal manner above the orifice. Because of the pressure gradients in the lower chamber the upper chamber pressure cannot be reliably calculated directly from downstream flow. However, the ratio of downstream to upstream flows, $R_f = Q_l/Q_u$, required to generate the same pressure, can be experimentally determined for flows well above the lower limit of the flowmeter. If the turbomolecular pump speed remains constant as the pressure is reduced the measured R_f and Q_l can be used to calculate an equivalent Q_u so,

$$P_u = \frac{Q_l R_p}{C R_f (R_p - 1)} \quad (2)$$

We have indirectly determined that the pump speed remains constant to within 2% down to 10⁻⁶ Pa and have obtained ion gauge calibration data that are reproducible to within 2% down to this same pressure.

The upper limit of this standard is determined by errors in the calculated conductance due to molecule-molecule collisions. This amounts to about 1.2% for nitrogen at 10⁻¹ Pa.

The error analysis of this standard is still underway, but at this time the largest systematic error is due to the measured fill pressure of the constant pressure flowmeters. Our preliminary estimate of the total uncertainties of this standard for nitrogen are 2.5% at 10⁻¹ Pa, 1.5% at 10⁻² Pa, 1.4% at 10⁻⁴ Pa, and 3.4% at 10⁻⁶ Pa.

¹K. F. Poulter, J. Phys. E 10, 112 (1983).

²C. R. Tilford, J. Vac. Sci. Technol. A 1, 152 (1983).